Princeton Fusion Experiment

I would like to correct several statements and point out important omissions in the article "Report of fusion breakthrough proves to be a media event" by William D. Metz (News and Comment, 1 Sept., p. 792).

- While the Alcator device at MIT holds the record value of density-confinement time product, it has never held the "nearness-to-breakeven" record. This quantity is usually measured by Q_p, the ratio of equivalent fusion power in deuterium-tritium operation to plasma heating power. The maximum value of Q_p obtained in the ohmic-heated Alcator has been 4×10^{-5}. In the autumn of 1977, the Princeton Large Taurus (PLT) with 1 megawatt of neutral beam injection obtained a Q_p of 0.002. In the PLT experiments of July and August 1978, with 2 megawatts of neutral beam injection, Q_p was increased to at least 0.008.
- The tokamak was not "invented in 1968," but in fact was under development in the Soviet Union in the mid-1950's. It was in 1968 that the Soviets reported the startling results from their T-3 machine, which clearly established the tokamak as the front-runner of all controlled fusion concepts. This event has since been matched in importance in toroidal fusion research only by Alcator achieving, in 1975, a density-confinement time product of 1×10^{13} cm^{-3} sec, and by the PLT results of 1978 (*1*).
- The exposure of the once-feared trapped-ion instability as a chimera is certainly an important result of the PLT experiments. However, if your reporter had questioned a number of practical fusion researchers, as distinct from theoreticians with arcane interests, he would have learned that a far greater concern was the ability to control impurity influx into the plasma before and especially during intense neutral beam injection. In previous beam injection experiments on many tokamaks, the electron temperature had been "clamped" by impurity-ion radiation, and power drain to colder electrons limited the temperature attained by the ions. The PLT experiment (*1*) demonstrated that, by using a material of low atomic number (carbon) for the discharge limiter and by wall gettering, harmful impurity-atom influx during intense beam injection can be suppressed, thereby clearing the way to achieving reactor-level temperatures (more than 60×10^6 K for the ions, and more than 40×10^6 K for the electrons).
- The PLT achievement was of a qualitative as well as a quantitative kind. For the first time the bulk plasma temperature was sustained by (beam-injected) superthermal ions whose power input exceeded the ohmic-heating power by a large factor (up to 5)—precisely the heating method required in tokamak reactors, where up to 100 percent of the superthermal ions can be produced by the fusion reaction itself. It was demonstrated with the PLT that reactor-level temperatures of both ions and electrons can be obtained without interference by the various instabilities that had also been predicted to be inherent to the beam-heating method. Surprisingly, your article does not even mention neutral beams.

Details of the PLT results were released for the first time on 23 August 1978 at the International Atomic Energy Agency Conference on Controlled Nuclear Fusion Research (*1*).

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References

1. H. P. Eubank *et al.*, Paper IAEA-CN-37/C-3, presented at the 7th International Conference on Controlled Nuclear Fusion, Innsbruck, Austria, 1978.

The statement that MIT's Alcator still holds the nearness-to-breakeven record is based on two measures of fusion performance enumerated by Lawson in 1955 and widely used by fusion researchers to mark their progress since then, namely, temperature and the product of density and confinement time. The idea of using a single, composite criterion is more recent, and there is no consensus about which one to use. But any measure that gives equal weight to the two Lawson measures (*1*) shows that the Alcator holds a marked advantage because of its superior density-confinement time product (which reached 3×10^{13} cm^{-3} sec in 1977 compared to 3×10^{11} for the PLT in 1978).

In any case, the energy gain criterion (Q_p) proposed by Jassby favors neutral beam-heated experiments and gives them an advantage over ohmic-heated experiments that would not carry through if both types of experiments were incorporated into a fusion reactor. The reason for this is that, in tokamak experiments heated with powerful neutral beam guns, a great deal of the equivalent fusion power comes from reactions that occur as the beams hit other beams and hit the bulk plasma, but very little power comes from the bulk plasma itself. Yet in an operating tokamak fusion reactor designed to produce electricity, the neutral beam guns will only be turned on for a short time to heat the plasma to its ignition temperature, and the source of fusion power will then be the "burning" bulk plasma. Thus the dominant power component in the Princeton experiment has little practical significance. According to H. Eubank at Princeton, beam-beam and beam-bulk reactors accounted for up to 99 percent of the equivalent fusion power from the PLT, and the bulk plasma accounted for about 1 percent. In the Alcator, which had no neutral beam guns, the bulk plasma accounted for all the equivalent fusion power.

The Q_p criterion, as calculated by Princeton researchers, shows the energy gain of the PLT approaching 1 percent. This figure is apparently the ratio of all the equivalent fusion power (20 kilowatts according to Eubank) to the neutral beam power that actually entered the tokamak (2 megawatts). But other sources of power were needed for heating the plasma. The beam guns, which were only 33 percent efficient, actually consumed 6 megawatts of power. The transformer, which induced the current circulating through the toroid, consumed 20 to 30 megawatts according to Eubank. Finally, the toroidal field coils, which generate the basic toroidal plasma shape, consumed 150 to 200 megawatts.

A more realistic Q for the PLT experiment would count as power output only the bulk fusion power and would include among the power inputs all the beam power plus the transformer power, at a minimum. (Both Princeton and MIT researchers argue that the huge toroidal field power should not be counted because the toroidal field coils in a practical reactor would be superconducting.) By such a Q criterion, the energy gain of the PLT would be 8×10^{-6} (200 watts per 25 megawatts), on the same order as the 1975 Alcator result.

The firsts that the PLT achieved with neutral beams—producing a relatively impurity-free plasma and showing that there were no beam-induced instabilities—were indeed notable and auspicious for future beam experiments. But it is generally acknowledged that the neutral beam technology used at Princeton (based on positive ions) cannot be extrapolated to a reactor-level plasma because the already modest efficiency plummets when the beam energy is raised. [*Science* discussed neutral beam technology when it was novel 3 years ago (Research News, 7 Feb. 1975, p. 422).] Finally, a notable outcome of the same meeting where the PLT results were presented was the idea that any type of neutral beam gun may be rendered inoperable in a reactor environment because there may be no way to stop thermonuclear neutrons from escaping through the neutral beam ports and disabling the guns.

—WILLIAM D. METZ

References

1. J. R. McNally, *Nucl. Fusion* **17**, 6 (1977).

Helping Soviet Scientists

I should like to make some suggestions with regard to the letters and commentary published on the Russian situation (11 Aug., p. 482). I think I am qualified to advise in this area, as I spent 45 years in Russia (five of which were spent waiting for an exit visa to Israel) and was interrogated, arrested, and imprisoned there for my activities as a refusenik scientist. Additionally, the current group of refusenik and imprisoned scientists is comprised largely of my friends. Following are some suggestions which I would make to Western scientists visiting the U.S.S.R.

1) Do not ask Soviet scientists for advice. Some of those who are less careful in what they say (such as the colleagues of Dale P. Cruikshank) may be in trouble in the long run—in this case after the publication of a letter in *Science*. Those who are more guarded—as were the colleagues of Charles DeLisi—are probably not telling the full story.

2) Anyone who does not already possess a fairly profound knowledge of Russian life probably should not try to decide what to do by himself, bearing in mind the maxim that a disease cannot be cured except by a physician. In this instance, the "physicians" are, for instance, those who belong to the Committee of Concerned Scientists (the director is Mark Mellman, 9 East 40 Street, New York 10016). My own ideas on this point are presented in (*1*).

3) It should be borne in mind that dissident scientists are still scientists. They write papers, but they write them in a Russian style and with flawed English; they cannot prepare the papers properly, and their correspondence with scientific journals is cut off. It would be helpful if someone could assist in the preparation of their manuscripts. I have papers right now from, for example, Y. Orlov, V. Brailovsky, and I. Brailovsky. Volunteers from various fields of science (physics, mathematics, cybernetics) are badly needed, since each published paper of a dissident scientist is the result of someone's good will and devotion. Interested persons should contact Mark Mellman at the address above.

4) "Excluded scientists" will be organizing an International Conference on Collective Phenomena in Moscow on 27–29 December. The participation of Western scientists will be extremely important and effective so far as support is concerned, because those in the Soviet Union have been deprived of scientific communication. Information about the conference is available from Minko Balkanski, co-chairman, Université de Paris VI, 4 Place Jussieu, 75230 Paris Cedex 05, France.

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The Brains of Geniuses

It is both easy and appropriate to deride the naively mechanistic notion that science might trace the cause of mental or moral excellence to the gross physical structure of a preserved brain (*1*). Thus, Einstein's genius remains elusive—and his brain remains in a cider box because no one has identified anything unusual about it worth publishing. As historical precedent for a negative result, Nicholas Wade (News and Comment, 25 Aug., p. 696) cites Rudolph Wagner's comparison of a laborer's brain with that of the great mathematician Friedrich Gauss. Wagner found no difference.

Yet Gauss's brain did not rest in a beer keg, and Wagner's results were dismissed by all the great craniometricians who made racism a respectable science in the 19th century. The dissection of brains from "eminent men" became a cottage industry among anatomists and anthropologists: they pledged themselves to each other and practically solicited subscriptions. "To me the thought of an autopsy is certainly less repugnant than I imagine the process of cadaveric decomposition in the grave to be," cajoled one famous enthusiast (*2*). Gauss's brain, at the Columbian value of 1492 grams, was only modestly overaverage, but he was too magnificent a genius to lose for the cause. So Paul Broca, the world's leading craniometrician, mentioned Gauss's advanced age (78) and small stature and jacked the figure up (*3*). The American E. A. Spitzka summa-